Bn 3499. MPS

PATENT SPECIFICATION

NO DRAWINGS

1,133,113

1,133,113

Date of Application and filing Complete Specification: 3 Feb., 1966.
No. 4867/66.
Application made in United States of America (No. 430764) on 5 Feb., 1965.
Complete Specification Published: 6 Nov., 1968.

Index at acceptance:—C7 A(B249, B25Y, B25X, B289, B309, B319, B32Y, B325, B327, B329, B349, B35Y, B359, B36X, B361, B363, B37Y, B38X, B381, B383, B385, B399, B419, B42Y, B431, B433, B435, B437, B439, B459, B46Y, B485, B487, B489, B50Y, B515, B517, B519, B52Y, B537, B539, B54Y, B548, B549, B559, B610, B613, B616, B619, B62X, B620, B621, B624, B627, B630, B635, B66Y, B66X, B661, B663, B665, B667, B669, B670, 740, 741, 742, 743, 744, 745, 770, 781, 782, 783)

Int. Cl.:—C 22 c 21/00

COMPLETE SPECIFICATION

Improvements in Forged Aluminium Base Alloy Members

We, ALUMINUM COMPANY OF AMERICA, a Corporation organized under the laws of the State of Pennsylvania, United States of America, of Alcoa Building, Pittsburgh, Pennsylvania, United States of America, do hereby declare the invention, for which we pray that a Patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to aluminium base alloy forged members having improved resistance to stress corrosion.

For some time aluminium base alloy members containing copper, magnesium and manganese have found considerable acceptance for various structural purposes. One such alloy known in the art contains nominally 4.5% copper, 1.5% magnesium and 0.6% manganese and carries the Aluminum Association designation of 2024 alloy. In the past this alloy has mainly been used in plate form which exhibits outstanding tear resistance and toughness, a very good strength to weight ratio and good resistance to general and stress corrosion especially in thin sections which are not stressed in the short transverse direction. Recently it has been determined that this type alloy has considerable potential in forged members in that such members exhibit, in general, the same highly desirable general mechanical properties as exhibited by the plate form. One further advantage in providing these forged members is that they are often used in conjunction with plate members in fabricating a structure and it is often desirable that all the members in a given structure have the same, or at least highly similar, alloy composition. However, forged members of the described type alloy tend to exhibit a marked susceptibility to stress corrosion type failures when the stress is applied in a short transverse direction. Results of accelerated alternate immersion tests conducted in 3.5% aqueous sodium chloride solution revealed stress corrosion failures at stress levels as low as 35% of the yield stress and lower and that such could occur in as short a time as three days. These results are considered to be a reliable indication of the performance to be expected of these forged members in that they exhibit a degree of susceptibility to stress corrosion which would make their use highly objectionable for many applications. As explained in more detail hereinafter, almost all forgings exhibit some short transverse directional properties and hence present this problem.

We have discovered that certain highly critical composition limits over and above those currently recognized in the art will impart substantial immunity to short transverse stress corrosion in forged members of the described alloy type, such that in accelerated alternate immersion stress corrosion tests, at stress levels of 50% and 75% of the yield strength the forgings have exhibited substantially no failures for periods of at least 30 days. This is considered to be a reliable indication of substantial immunity to stress corrosion in these members under ordinary service conditions.

Accordingly it is the primary object of the invention to provide forged members of the alloy type described which possess sub-

[Price 4s. 6d.]

stantial immunity to short transverse stress corrosion.

Other objects will, in part, be obvious and will, in part, appear hereinafter.

In referring to forgings, the invention contemplates any forged member including both die and hand forgings. For example, an ingot or other body of suitable size may be formed into an intricate shape by die forging wherein a body cast in a special shape or even a flat or round body is subjected to one or more compressions between a series of blocker and finish dies which gradually approach the final configuration. Another example is a member formed by progressively compressing an ingot between two relatively flat die faces in a forging press. The products of such operations are generally referred to as hand forgings in the art and include a variety of standard and special shapes. Standard shapes include multifaced rounds, rectangles, biscuits and other simple shapes well known in the forging practice. By suitable manipulation of the member within the forging press or hammer more complex hand forging shapes may be formed such as stepped, wedged, "I", multiple raised face and various other useful configurations. The forged member may be subsequently rolled, extruded, spun, bent, sawed, punched, machined, or otherwise processed as desired to facilitate its ultimate or end configuration and use and reference to forged members is intended to include such members subjected to additional fabrication steps. Of course, these operations often precede thermal treatment if desired. For instance, slab type hand forgings are often hot rolled into plate and then solution heat treated, quenched and artificially aged. Also, a hand forged member may, if desired, be used as stock for a die forging operation.

As indicated at the outset of this description, the susceptibility to stress corrosion observed in forgings of the described type alloy is encountered in the short transverse direction. When referring to the short transverse direction with respect to forgings, such is intended to mean a direction as revealed by the grain structure and not necessarily the shortest dimension of the member. In an elongated flat slab type of forging, this direction most often coincides with the thickness, as is the case with plate or sheet, and it is therefore easily recognized. The short transverse direction can vary widely when the forged shape deviates from this straight forward configuration as where the cross section of the forgin is relatively symmetrical or where the forging has a relatively complex shape. Further, the short transverse direction in one portion of a forging can vary considerably from that in another portion as is described in more detail hereinafter. However, the short transverse direction can be readily determined by macro examination of the grains and by testing various properties including mechanical and stress corrosion properties, and hence can be ascertained for a given portion of a forging by those skilled in the forging art.

An interesting situation arises with a hand forging of relatively symmetrical cross-section, say 4 inches square, which may be viewed at first glance as having no short transverse direction, at least if such is predicated upon an analogy to plate. However, when the grain structure is examined, it reveals that while the extent of the short transverse structure is not as pronounced as that observed in highly worked flat members, the grains do exhibit a generally short transverse type structure the extent of which is dependent on the amount of work imparted to the member. Also, the grain structure generally lacks any long transverse characteristic and certainly has a longitudinal characteristic. In such a case, for purposes of this description, the body is considered to exhibit substantially short transverse grain structure in any orientation transverse to its axis although to a lesser degree than that observed in flat shapes. This is verified by macro examination and by measuring mechanical properties and stress corrosion effects in various elongated forgings having relatively symmetrical cross-sections. These tests indicate that cross-sectional specimens taken at various orientations all exhibit properties closely approximating those generally associated with the short transverse direction in flat members.

Even relatively flat slab type forgings sometimes defy complete analogy to plate regarding short transverse grain orientation. As is generally known in the art, a flat slab having a cross-section of say 4 inches by 6 inches can, by appropriate forging sequence, exhibit short transverse grain structure across either the 4 inch or 6 inch dimension or both. Again, these effects can be verified by macro examination and tests measuring mechanical and stress corrosion properties. Further, a flat forging will often exhibit a pronounced short transverse grain structure across its thickness and also, across its width, a partially short transverse characteristic in its grain structure in lieu of the expected pronounced long transverse structure. Again, this effect can be verified by macro examination together with mechanical and stress corrosion tests.

A further complication arises in the case of a more completely worked and shaped forging which can exhibit varying short transverse directions at different portions thereof. While this effect is generally insignificant in simple hand forging shapes, it can be very pronounced in more complex hand forged

shapes and especially in die forgings where metal is often caused to move in different directions and at varying rates thereby giving rise to short transverse grain structures of varying extent and direction throughout the forging. Basically the short transverse grain structure will prevail transversely to a region of high metal movement and will generally coincide with the region where the grains become elongated and are compressed as they flow under pressure. For instance, a bar is made into a valve body by die forging between two contoured die surfaces. When the bar is compressed between the opposing dies, some of the metal is extruded or caused to flow as "flash" into the gutters disposed at the parting line of the dies and perhaps into a gutter exit gate. This metal movement or flow orients the grains such that a short transverse structure prevails in a direction across this flash line which coincides with the direction in which the grains were compressed as they moved through the flash, or gutter, area. Again, this effect is verified by macro examination and by mechanical and stress corrosion tests where the structure generally exhibits severe susceptibility to stress corrosion cracking. If the valve body has a pronounced neck or other protrusions, similar zones of short transverse grain structure, sometimes of varying degree and direction, will also be observed. While the alloy type described is frequently forged into larger structural shapes, the valve body illustration is set forth to amplify the general description concerning short transverse orientation in more complex forged shapes. One additional factor influencing metal movement is the shape of the forging stock prior to forging. Of course, differently shaped stock used to form a given forged shape will flow in varying directions and to varying degrees. Hence, different grain patterns in like forged shapes are often traced back to the forging cycle as affected by the stock employed.

It is this short transverse grain structure, almost always observed in forged members, which exhibits the impaired resistance to stress corrosion thereby rendering forged members of a described type alloy unsatisfactory for severe service requirements. Hence, the invention will benefit any member which exhibits an internal structure having a substantially short transverse grain configuration as a result of a forging operation. By a substantially short transverse grain configuration is meant that this characteristic is of sufficient extent as to exhibit the susceptibility to stress corrosion associated with short transverse grain structures produced by forging. If significant metal working operations other than forging are performed in fabricating the member, its internal structure will be influenced by both the forging and the other operations and the invention applies to such in that the internal structure is effected substantially by forging.

According to the present invention there is provided a forged aluminium base alloy member at least a portion of said member having an internal structure comprising a substantially short transverse grain configuration substantially produced by a forging operation as hereinbefore defined, said member being formed of an alloy containing 3 to 6 weight % copper, 0.8 to 3 weight % magnesium, and 0.3 to 1 weight % manganese, the balance except for impurities and incidental elements being aluminium, the minimum magnesium content being governed by the relation:

Mg min.=0.32 Cu when Mn does not exceed 0.5%; and

Mg min.=0.2+0.32 Cu—0.4 Mn when Mn is greater than 0.5%,

the said member exhibiting substantial immunity to stress corrosion in the short transverse direction as hereinbefore defined at a stress up to 50% of the yield level in the said short transverse direction.

From a composition standpoint the alloy used in making forged members in accordance with this invention consist, on a weight basis, of aluminium, 3 to 6% copper, 0.8 to 3% magnesium and 0.3 to 1% manganese. A preferred set of ranges is 3 to 5% copper, 1 to 2% magnesium and 0.3 to 1% manganese. Generally speaking the impurity limits associated with the described type alloy preferably apply to the practice of the invention. Thus the following maximum impurity limits are generally followed: silicon 0.5%, iron 0.5%, chromium 0.1%, and zinc 0.25%. A preferred composition is aluminium, 4.15 to 4.60% copper, 1.45 to 1.65% magnesium, 0.5 to 0.65% manganese, together with the following maximum limits on impurities: silicon 0.15%, iron 0.25%, chromium 0.10%, zinc 0.20%, and nickel 0.05%. To these compositions incidental elements may be added such as up to 0.05% titanium and 0.002% boron for grain refining purposes. A further composition limit, over and above that practised in the prior art, which is required by the practice of the invention is a highly critical relation between the principal alloying constituents, copper and magnesium. Broadly speaking the minimum magnesium content is equal to 0.32 times the copper content except that where the manganese content exceeds 0.5% this minimum may be reduced slightly as explained further hereinafter. Preferably the magnesium content is at least 0.2% above this minimum. Within the broader range (minimum magnesium= 0.32 copper) forged members of the described alloy will exhibit substantial immunity to stress corrosion under stresses up to or slightly

exceeding 50% of the yield strength, for example, a stress level of about 30 K.s.i. based on a nominal yield strength of 60 K.s.i. for thermally treated 2024 aluminium alloy. The additional 0.2% magnesium in accordance with the preferred practice of the invention raises the permissible stress level to up to or slightly exceeding 75% of the yield strength, a stress level of about 45 K.s.i. for 2024 aluminium alloy. These conclusions are based on accelerated alternate immersion tests in a 3.5% sodium chloride aqueous solution.

An important modification to the basic magnesium and copper relationship occurs where manganese exceeds 0.5%. For this higher manganese content, the minimum magnesium necessary to maintain substantial immunity to stress corrosion is slightly lessened. Accordingly the following equations govern the minimum magnesium content in accordance with the invention where stress levels do not exceed 50% of the yield strength by a substantial amount:

(1) Min. $Mg=0.32$ Cu where $Mn<0.5\%$
(2) Min. $Mg=0.2+0.32$ $Cu-0.4$ Mn where $Mn>0.5\%$

Under the preferred practice of the invention where the applied stress can equal and even slightly exceed 75% of the yield strength, the equations become:

(3) Min. $Mg=0.2+0.32$ Cu where $Mn<0.5\%$
(4) Min. $Mg=0.4+0.32$ $Cu-0.4$ Mn where $Mn>0.5\%$.

The alloy forging stock used in accordance with the invention is generally continuously cast ingot of suitable size to be used in the forging operations. Of course, ingot stock is generally scalped to remove serious surface defects and cropped to remove end defects as is the general practice in the forging art. However, the use of ingot stock is not a limitation on the invention which contemplates the use of any alloy body adapted to the particular forging operations contemplated. For instance, in making relatively small hand and die forgings small rolled rounds and the like can often be employed. Generally the ingot or other body is subjected to a thermal treatment which homogenizes its internal structure and relieves internal stresses prior to being forged. This treatment may generally be accomplished by a prolonged exposure for example over 10 hours, at a temperature exceeding 850°F., although a 20 to 25 hour soak at a temperature of 900° to 925°F. is more often used. However, even longer exposure times of up to 50 hours and longer are often employed. The duration of this treatment is expressed functionally as being sufficient to effect substantial solution of the soluble alloy constituents. The forging operations are generally performed at elevated, or hot working, temperatures of 600° to 900°F. although more often between 700° and 900°F. as is the general practice in the art.

To approach the useful strength potential of the described heat treatable alloys, they are solution heat treated and artificially aged in accordance with general methods known in the art. Thus, the forged member is solution heat treated at a temperature of 850° to 950°F. for a hold time of 1 to 12 hours or longer, the hold time, of course, being to some extent a function of the size of the member. The temperature hold time is described functionally as of sufficient duration to effect substantial solution of the soluble alloy constituents. The forging is then quenched to retain the solution effects of this treatment; the means used in quenching are generally determined by the size of the forging, simple water immersion being adequate for a forging of relatively small size and spray quenching being more appropriate for a thicker member in order to rapidly cool its entire thickness. The forging is then artificially aged at a temperature generally ranging from 300° to 400°F., and a hold time of 6 to 20 hours although narrower ranges of 360° to 390°F. and 10 to 13 hours are more often employed. If desired, the quenched forging can be slightly cold worked prior to artificial aging. The cold working is generally accomplished by compressing, or sometimes possibly stretching, the member at substantially room temperature and serves to mechanically relieve internal stresses and imparts other benefits known in the art. By substantially room temperature is generally meant 60° to 100°F. for hand forgings and sometimes slightly higher for die forgings in that the dies are often heated to 100° to 150°F. prior to the cold reduction. This step is, of course, more feasible with hand forgings because of their relatively simple shapes as opposed to die forgings which often have intricate shapes which would be excessively disturbed by any cold working. Further, in a complex die forging achieving a specific degree of metal working uniformly throughout is often quite difficult. Of course, when a die forging is to be cold worked such as usually performed by compressing such in finish dies. Hence, the forgings are preferably compressed in a suitable forging operation performed at room temperature to effect a permanent reduction in thickness of up to 5%, e.g. 2% to 5%, or stretched to effect a permanent stretch of up to 3%, e.g. 1½% to 3%, where such is feasible. It appears that this substantially room temperature working, in addition to imparting stress relief and the other generally recognized benefits, also can exert an in-

fluence on resistance to stress corrosion in that hand forgings in this temper often exhibit slightly better resistance to stress corrosion than do die forgings which are more often not so treated. Hence hand forgings represent a preferred embodiment of the invention because of the consistently good results experienced therewith. Our invention is illustrated in the following examples:

EXAMPLE 1

A group of ingots were prepared from alloys having compositions within the preferred range composed of aluminium, 4.15 to 4.60% copper, 1.45 to 1.65% magnesium, 0.5 to 0.65% manganese, with the following maximum impurity limits: silicon 0.15%, iron 0.25%, chromium 0.1%, zinc 0.2% and nickel 0.05%. The ingots also contained up to 0.05% titanium and up to 0.002% boron for grain refining purposes. The ingots were continuously cast in the shape of cylinders, which, after scalping, were about 19 inches in diameter and were cut to lengths of about 54 inches. Each ingot section was homogenized by a 20 to 25 hour soak at a temperature of 900° to 925°F. While still hot, the ingot sections were transferred to a forging press, and compressed in an axial direction at a temperature of from 850° to 900°F. to form a biscuit about 24 inches high and 24 inches in diameter. The biscuit was "squared" on the press to form two parallel sides and further drawn down into a hand forging having the shape of an elongated slab about 20 inches wide, 130 inches long and 4 inches thick. The slab was solution heat treated at 900°F. for 20 hours, spray quenched, compressed at room temperature to effect a 3% permanent reduction, and then artificially aged at 370° to 385°F. for 10 to 13 hours. Short transverse tensile specimens taken from these slabs were subjected to accelerated stress corrosion tests by alternate immersion at different stress levels in a 3.5% aqueous sodium chloride solution. All the forgings had a magnesium content above the minimum requirements of this invention and, they exhibited substantial immunity to stress corrosion at stress level of 50% of the yield stress in that the specimens survived the accelerated tests for at least 30 days. Further, the specimens whose minimum magnesium content satisfied the requirements of equations (3) and (4) were found to exhibit this same immunity at a stress level of 75% of the alloy yield stress.

As a standard of comparison, a similar slab containing aluminium, 4.6% copper, 1.4% magnesium and 0.5% manganese was formed by the same method as set forth earlier in this Example. Short transverse specimens taken across the thickness of this slab were found to exhibit marked susceptibility to stress corrosion in that almost all the specimens failed during the accelerated stress corrosion tests and at stress levels of 50% of the short transverse yield strength and lower.

At this point it is worthwhile to note that a considerable quantity of flat or slab type hand forgings have been produced using the preferred composition limits set forth at the outset of this example and that these particular members have proved consistently superior in resistance to stress corrosion over other similar members of the described type alloy without the critical composition control set forth herein and hence such slabs having a thickness generally ranging from 1 inch to 6 inches represent a preferred embodiment of the invention. These slabs may be machined, bent, or otherwise further processed although such other fabrication steps most often precede thermal treatment. Further, forged slabs of this alloy composition have been hot rolled into plate having improved mechanical properties over similar plate hot rolled from ingot stock without a preliminary forging operation. This forged and rolled plate exhibited the same immunity to stress corrosion as did the forged slab. Hence this forged and rolled plate likewise represents a preferred embodiment of the invention.

EXAMPLE 2

An ingot about 6 inches in diameter and about 55 inches long, and containing aluminium, 4.3% copper, 1.5% magnesium and 0.5% manganese, is flattened across a diameter in a forging press to form a slab hand forging about 4 inches thick. This member is then used as stock in a die forging operation to form an aircraft wing span about 48 inches long, about 18 inches wide at one end, tapering slightly to about 14 inches at the other end, and having a considerable number of webs and reinforcing flanges and ribs. The thickness of this span varies from about 1 inch at its thinnest, or web, portion to about 5 inches at some of the rib regions.

The die forging sequence includes heating the slab to about 850°F. and compressing between blocker dies which roughly approximate the final shape. The flash extruded at the parting line between the dies is removed and the piece reheated to 850°F. and pressed between another pair of blocker dies more closely approximating the details of the final configuration. Again, the flash is removed and the piece reheated to 850°F. and compressed between a pair of first finish dies which very closely approximate the details of the final configuration. The piece is then solution heat treated at a temperature of 900° to 925°F. for about five hours hold time and rapidly quenched. The piece is then compressed in a pair of final dies at substantially room temperature to effect a per-

manent deformation of about 2% thus forming the final shape. This span has a number of ribs, flanges, webs, bosses and similar variations in section which exhibit different degrees of short transverse structure depending on the extent and severity of metal movement involved in forming such. Short transverse specimens are taken from these various points and subjected to accelerated stress corrosion tests. The results of these tests indicate substantial immunity to stress corrosion in that almost all the specimens survive the tests for at least thirty days and at stress levels of 50% of the short transverse yield strength. Further, where the alloy composition of the die forged span is modified to include 1.65% magnesium thus satisfying the requirements of equation (3), specimens are found to exhibit the same substantial immunity to stress corrosion at stress levels equal to 75% of the short transverse yield strength.

WHAT WE CLAIM IS:—

1. A forged aluminium base alloy member at least a portion of said member having an internal structure comprising a substantially short transverse grain configuration substantially produced by a forging operation as hereinbefore defined, said member being formed of an alloy containing 3 to 6 weight % copper, 0.8 to 3 weight % magnesium, and 0.3 to 1 weight % manganese, the balance except for impurities and incidental elements being aluminium, the minimum magnesium content being governed by the relation:

Mg min.=0.32 Cu when Mn does not exceed 0.5%; and
Mg min.=0.2+0.32 Cu−0.4 Mn when Mn is greater than 0.5%,

the said member exhibiting substantial immunity to stress corrosion in the short transverse direction as hereinbefore defined at a stress up to 50% of the yield level in the said short transverse direction.

2. A forged aluminium base alloy member according to claim 1, wherein said copper is present in an amount of from 3 to 5 weight %, magnesium is present in an amount of from 1 to 2 weight %, and manganese is present in an amount of from 0.3 to 1 weight %.

3. A forged aluminium base alloy member according to claim 1 or 2, wherein the member exhibits substantial immunity to stress corrosion, in the short transverse direction as hereinbefore defined, at a stress of up to 75% of the yield level in the said short transverse direction and wherein the minimum magnesium content is governed by the relation:

Mg min.=0.2+0.32 Cu when Mn is not greater than 0.5%,
Mg min.=0.4+0.32 Cu−0.4 Mn when Mn is greater than 0.5%.

4. A forged aluminium base alloy member according to claim 1, 2 or 3, wherein the said internal grain structure has been substantially effected by initially upsetting elongated stock in the lengthwise direction by forging, further forging the upset product to form a member having a short transverse section, solution heat treating said member at 850° to 950°F., quenching, working said member at substantially room temperature as hereinbefore defined to effect a permanent deformation of up to 5%, and thereafter artificially aging said quenched and worked member at 300° to 400°F.

5. A forged aluminium base alloy member according to claim 4, wherein said member has been subjected to a homogenizing treatment comprising exposure for a prolonged period of time at a temperature exceeding 850°F.

6. A forged aluminium base alloy member according to any one of claims 1 to 5, wherein the forging operations impart to said member a flat slab type configuration.

7. A forged aluminium base alloy member according to any one of claims 1 to 5, wherein said member is a hand forging which has been forged between substantially flat dies.

8. A forged aluminium base alloy member according to claim 4 or claim 4 and either of claims 5, 6 or 7, wherein said member has been cold worked prior to artificial aging.

9. A forged aluminium base alloy member according to claim 1, substantially as hereinbefore described with reference to the Examples.

STEVENS, LANGNER, PARRY & ROLLINSON,
Chartered Patent Agents,
Agents for the Applicants.

Printed for Her Majesty's Stationery Office by the Courier Press, Leamington Spa, 1968.
Published by the Patent Office, 25, Southampton Buildings, London, W.C.2, from which copies may be obtained.